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ORIGINAL RESEARCH

Risk factors for positioning-related somatosensory evoked potential changes in 3946 spinal surgeries

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Abstract
The goal of this study was to evaluate the risk factors associated with positioning-related SSEP changes (PRSC). The study investigated the association between 18 plausible risk factors and the occurrence of intraoperative PRSC. Risk factors investigated included demographic variables, comorbidities, and procedure related variables. All patients were treated by the University of Pittsburgh Medical Center from 2010 to 2012. We used univariate and multivariate statistical methods. 69 out of the 3946 (1.75%) spinal surgeries resulted in PRSC changes. The risk of PRSC was increased for women ($p < 0.001$), patients older than 65 years of age ($p = 0.01$), higher BMI ($p < 0.001$) patients, smokers ($p < 0.001$), and patients with hypertension ($p < 0.001$). No associations were found between PRSC and age greater than 80 years, diabetes mellitus, cardiovascular disease, and peripheral vascular disease. Three surgical situations were associated with PRSC including abnormal baselines ($p < 0.001$), patients in the "superman" position ($p < 0.001$), and patients in surgical procedures that extended over 200 min ($p = 0.03$). Patients with higher BMIs and who are undergoing spinal surgery longer than 200 min, with abnormal baselines, must be positioned with meticulous attention. Gender, hypertension, and smoking were also found to be risk factors from their odds ratios.

Keywords Position-related changes · Intraoperative monitoring · Somatosensory evoked potentials

1 Introduction

Positioning of the upper extremities during lengthy spinal [1–3], neurosurgical [4], orthopedic [5], and cardiac [6] surgeries can predispose patients to upper extremity injury. Injury may be via stretch of peripheral nerves, compression or traction on peripheral nerves and plexus (caused by inadequately padding the upper extremities, use of tourniquets, or taping the shoulders), or indirectly from ischemia. The previously published rates of neurological injury due to positioning after surgical procedures range widely, from 0.14 to 37% [2, 7–9]. The reported incidence of perioperative peripheral nerve injury (PPNI) ranges from 0.033 to 0.10%; making it a rare but important perioperative complication resulting in significant patient disability, functional loss, and the potential for litigation [10]. The recovery process can take weeks to months despite rehabilitation with physical therapy [11]. In addition, PPNI may lead to increased length of hospital stay and increased anxiety regarding the prognosis [12]. Somatosensory evoked potential (SSEP) monitoring is a noninvasive method used to evaluate the functional integrity of the somatosensory system at the level of the peripheral nerves, brachial plexus, spinal dorsal columns, brainstem, thalamus and primary somatosensory cortex [13–18]. Intraoperative neurophysiological monitoring (IONM) utilizing SSEP changes has been reported to be useful in identifying when to reposition the patient during positioning changes during surgical procedures [2].

Studies have demonstrated risk factors for PRSC including hypertension, tobacco use, diabetes mellitus [9, 10], older age [19, 20] and obesity [21–25]. The aim of the current study was to investigate these and additional possible risk factors, specifically obesity, for PRSC. We considered

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the hypothesis that BMI is associated with the greatest risk of positioning-related SSEP changes in spine surgery. The potential correlation of obesity and other risk factors to physiologic change may assist in pre-operative evaluation and optimization of intraoperative positioning options for surgery.

2 Methods

2.1 Study population

Patients undergoing spinal surgical procedures with complete SSEP recordings at the University of Pittsburgh Medical Center (UPMC, Pittsburgh, PA) from 2010 to 2012 were included in the study. The spinal surgeries consisted of instrumented and non-instrumented fusions, decompressions, kyphoplasties, discectomies, and laminectomies among others. All 3946 patients had baseline recordings prior to positioning and continuous intraoperative SSEP monitoring during surgery. Patients undergoing lumbar or thoracolumbar surgeries were placed in the prone position with arms extended upwards ("superman position") and those undergoing high thoracic and cervical spinal surgeries were positioned in the prone position with their arms tucked to their sides. Patients without upper SSEP intraoperative monitoring, and patients whose positioning could not be fully ascertained from records were excluded from this study. This study identified the risk factors for upper extremity PRSC only. Please note that the overweight category excludes patients with obesity defined by BMI. Overweight was defined as a BMI of 25.0–29.9, and obese was characterized as greater than a BMI of 30.

2.2 Standard protocol approvals, registrations, and patient consents

This retrospective observational study was conducted with Institutional Review Board approval from the University of Pittsburgh (IRB #:PR008120394).

2.3 Intraoperative monitoring

All patients underwent IONM utilizing upper extremity (UE) SSEP recording. Stimulation was delivered bilaterally to either the ulnar (USP) or median nerves (MSP). First, adhesive pads were used per protocol, but if an optimal signal was not achieved, needle electrodes replaced them. Baseline UE SSEP values were obtained after the induction of anesthesia. Continuous bilateral upper and lower-extremity SSEP were obtained throughout the procedure though this study was limited to the analysis of UE SSEP data. In all cases, a board-certified neurophysiologist (American Board of Neurophysiological Monitoring) and a physician neurologist were available for data interpretation and consultation on-site and remotely [26].

We documented the specific surgical procedures performed, including approach, the characteristics and timing of all UE SSEP changes during the surgical procedures, the improvement in or lack thereof in SSEP responses after intervention, and the laterality of SSEP changes. Finally, we recorded the patients' postoperative neurological exam.

All patients were placed under general anesthesia using inhalational agents supplemented with intravenous agents. The patients mean arterial blood pressure as well as anesthetic levels were documented during the surgical procedures at 15 min intervals. SSEP changes were detected and communicated immediately to the surgical and anesthetic team. Most arm repositioning after a noted UE SSEP change was performed by the anesthesia team. In some instances, repositioning was performed by the neurophysiological technologist in the room.

2.4 Upper and lower extremity SSEPs

Upper extremity SSEPs were elicited using alternating stimulation delivered to the bilateral median and ulnar nerve at the wrist. Electrical stimuli consisted of rectangular pulses with a duration of 200–300 microseconds, frequency of 2–3 Hz, and a current intensity that was supra-threshold and ranged from 35 to 65 mA. Averaged SSEPs were computed from either 128 or 256 trials, depending on the signal quality [28]. The time base for SSEP data acquisition and display was set at 100 ms. Completed SSEP averages were recorded approximately every 45 s.

SSEP recordings were obtained from the scalp and cervical region using subdermal needle electrodes. Both P4/Fz and P3/Fz scalp montages were used for recording UE SSEPs and Pz/Fz and P4/P3 scalp montages were used for lower extremity cortical SSEPS. A cervical electrode was localized at the C7 spinous process or at the level of the mastoid (M) and referenced to Fz for brainstem/cervical recordings. UE peripheral nerve responses were recorded from the Erb's point for upper extremity SSEPs. Stimulation frequency was typically set to 2.43 Hz with duration of 200–300 μs. Band-pass filters were set at 30–300 Hz for cortical recordings and 30–1000 Hz for brainstem/cervical and peripheral recordings.

2.5 Group discrimination/alarm criteria

Baseline SSEP values were obtained after the induction of anesthesia. A significant SSEP change was defined as a persistent reduction in SSEP amplitude of 50% or more in the primary somatosensory cortical SSEP and/or a prolongation of SSEP peak latencies of greater than 10% from baseline

values, in two consecutive SSEP averages [27–31]. Both Erb and cervical recordings were also used for the detection of peripheral nerve injury.

We defined that a significant UE SSEP change was due to malpositioning when SSEP changes were unilateral and when these same SSEP changes improved, partially or completely, after a positioning intervention. Figure 1 demonstrates significant SSEP changes that were deemed secondary to malpositioning.

2.6 Statistical methods

Univariate and multivariate data analysis was performed. Descriptive statistics were computed by using crosstabs to show the relationship between PRSC and patient demographics. We compared the risk factors for position-related changes using the Chi square statistic and Fisher exact test if the expected counts were small. Odds ratios (OR) and confidence intervals (CI) were calculated for significant variables using standard methods.

Multivariate analysis [30] was performed to examine the effects of more than one risk factor at a time on position-related SSEP changes. We had sufficient data to examine 18 plausible risk factors. Due to the increased error that would have ensued from testing all the possibilities in multivariate logistic regression, we used a regression analysis with Bayesian shrinkage. Bayesian shrinkage reduces bias by adjusting all risk factors while stabilizing the model. We used this technique so that all potential confounders could be incorporated while allowing the model to converge while providing valid estimates [31–33]. Statistical analysis was performed using SPSS version 22 (IBM Corp., Armonk NY).

3 Results

3.1 Participants

We conducted a retrospective case study on 3946 patients who underwent spinal surgical procedures from 1/1/2010 to 8/24/2012 at UPMC. The criteria for the patient sample included all adult (age ≥ 18) and geriatric (age ≥ 65) patients who underwent spinal procedures in the prone position.

3.2 Descriptive statistics

The results for our univariate analysis are displayed in Table 1. Table 1 includes the odds ratios, descriptive statistics, and chi-Squared values.

Table 2 details the 69 patients with UE PRSC, including the type of procedure they underwent, side of change, stage of operation, and whether neurological deficits were detected post-operatively. Thirty-two (46.38%) patients had changes of the left side UE SSEPs, 36 (52.17%) patients had changes of the right-side UE SSEP and one (1.45%) patient had bilateral SSEP changes. We included this patient with bilateral changes because he or she had two independent SSEP changes on both sides. Both changes improved before the end of surgery. This patient was unique to have two changes, so we included he or she in the study. 5 of the 69 (7.25%) patients did not have a consistent measure of their erb's point channel. Of the 64 consistently measured

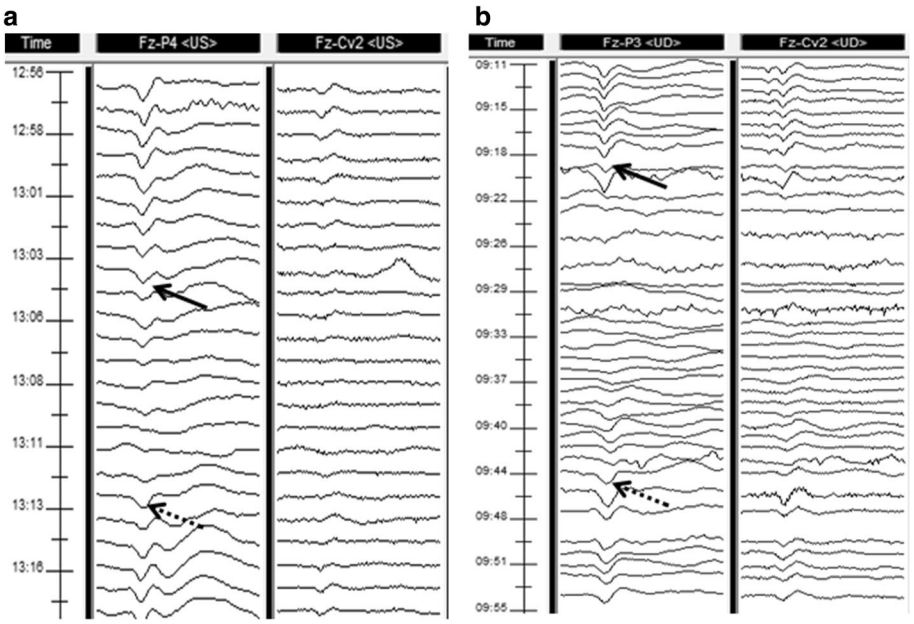

Fig. 1 **a** This image shows the cortical and subcortical waveforms of a patient's PRC. There was a decrease in US during positioning of the surgery. There was improvement when tape was released. The solid arrow shows where the change begins, while the dashed one shows where the change is resolved. Scale: 2.00 μV per division. **b** This also shows a patients' PRC. There was a decrease in response during exposure of the surgery. Additional padding improved the SSEP response, however SSEPs never returned to baseline. The solid arrow shows where the change begins, while the dashed one shows where the change improved. Scale: 2.00 μV per division

Table 1 Univariate odds ratios and descriptive statistics

Predictors	No changes n (%) 3877 (100%)	Significant changes (69 patients)	P value	Odds ratio
Female	1793 (50.4)	19 (30.6)	< 0.01	0.43 (0.25, 0.75)
Diabetes mellitus	673 (18.9)	21 (33.9)	< 0.01	2.19 (1.29, 3.74)
Hypertension	1912 (53.8)	42 (67.7)	0.03	1.80 (1.05, 3.08)
Cardiovascular disease	431 (11.9)	14 (22.6)	< 0.01	2.17 (1.19, 3.97)
Peripheral ventricular disease	98 (2.8)	3 (4.8)	0.33	1.79 (0.55, 5.81)
Smoke	894 (25.2)	10 (16.1)	0.1	0.57 (0.29, 1.13)
Home/nursing home	2722 (77.0)	43 (69.2)	0.16	0.68 (0.39, 1.17)
Age 65 and older	1050 (28)	22 (32.4)	0.43	1.23 (0.74, 2.06)
Age 80 and older	193 (5.0)	5 (7.2)	0.41	1.47 (0.587, 3.71)
Overweight	1141 (32.4)	10 (16.1)	< 0.01	0.40 (0.20, 0.79)
Obese	1469 (41.7)	40 (64.5)	< 0.01	2.54 (1.51, 4.30)
Abnormal baselines	2109 (58.7)	32 (46.4)	0.04	0.61 (0.38, 0.98)
Procedure time > 200 min	1407 (39.4)	33 (47.8)	0.16	1.41 (0.87, 2.27)
Procedure time > 400 min	93 (2.6)	4 (5.8)	0.1	2.30 (0.82, 6.45)
Superman position	2219 (57.2)	38 (55.1)	0.72	0.92 (0.57, 1.48)

This table shows the odds ratios and descriptive statistics from the univariate analysis of predictors and position-related changes

Table 2 Specifics of position related changes at different time points in surgery

Total number of changes n (%)	Positioning	Exposure	Instrumentation	Closing	N/A
Type of surgery					
Posterior spinal fusion n = 30 (43.50%)	1	13	13	1	2
Posterior cervical fusion n = 31 (44.90%)	21	2	5	2	1
Laminectomy n = 1 (1.40%)	0	0	1	0	0
Kyphoplasty n = 1 (1.40%)	0	0	1	0	0
Side of change					
Right n = 36 (52.20%)	9	9	15	2	1
Left n = 32 (46.40%)	13	7	9	1	2
[a]Bilateral change n = 1 (1.40%)	1	0	0	0	0
SSEPs back to baseline	91.30%	87.50%	87.50%	100%	66.67%

This table displays more information about each patient with positioning-related changes, including type of procedure, side and nerve of change, time of change, and whether he or she had post-operative neurological deficits. Posterior Spinal Fusions included transforaminal lumbar interbody fusions, posterior lumbar interbody fusions, lumbar interbody fusions, and posterior spinal fusions. The patients with post-operative deficits included both sensory and motor losses. All patients with significant changes had ulnar changes except for one. Please note that N/A in the table means that it was not specified when the position related change occurred during the surgery

[a]We included this patient with bilateral changes because he or she had two independent SSEP changes on both sides. Both changes improved before the end of surgery. This patient was unique to have two changes, so we included he or she in the study

patients, 54 (84.38%) patients had changes in their erb's point channel while 10 (15.63%) patients did not. The significant SSEP changes of 61 (88.4%) patients completely resolved intra-operatively with repositioning of the affected arm, 5 (7.2%) patients' SSEP changes moderately improved but remained changed with arm repositioning and 3 (4.3%) patients' SSEP changes did not improve until closure. Two of these 69 (2.90%) patients were found to have new post-operative neurological deficits that consisted of sensory and motor loss. Both patients had a decrease in amplitude in cortical, subcortical, and erb's point channels.

3.3 Risk factor analysis

Factors with a $p < 0.05$, odds ratio (OR) greater than 1, and a 95% confidence interval (CI) greater than 1 were classified as risk factors.

Our multivariate analysis yielded nine different factors that were associated with significant PRSC. Four demographic factors were associated with perioperative neurological deficit: female ($p < 0.001$; OR 4.86; 95% CI 2.92, 8.10), age over 65 years ($p = 0.01$; OR = 1.97; 95% CI 1.16, 3.35), overweight ($p < 0.001$; OR 11.45; 95% CI 5.94, 22.07), and obesity ($p < 0.001$; OR 2.72; 95% CI 1.79, 22.07). Two comorbidities were associated with neurological deficit: smoking ($p < 0.001$; OR 5.87; 95% CI 3.06, 11.29) and hypertension ($p < 0.001$; OR 2.15; 95% CI 1.42, 3.27).

3.4 PRSC

Three intraoperative factors were associated with PRSC: abnormal SSEP baselines ($p < 0.001$; OR 3.50; 95% CI 2.27, 5.40), the "superman" position ($p < 0.001$; OR 2.70; 95% CI 1.77, 4.12), and procedure times greater than 200 min ($p = 0.03$, OR 1.61; 95% CI 1.05, 2.47). No associations were found between PRSC and age greater than 80 years, diabetes mellitus, cardiovascular disease, and peripheral vascular disease. Table 3 displays these results.

4 Discussion

Our results demonstrate that a higher BMI is associated with the most significant increased risk of PRSC. Patel et al. demonstrated that extreme obesity (BMI > 40) was related to surgical complications [23]. Obese patients require an increased amount of anesthetic which can cause changes in pressure and may impair anesthesia management, leading to positioning-related changes [23, 34]. The association between obesity and operative complications has been studied by many [21–23, 25]. Specifically, Patel et al. studied 86 patients who underwent spinal surgeries and reported a correlation between increasing BMI and increased risk of significant post-operative complications ($p < 0.04$).The risk of significant complications was 14% with a BMI of 25, 20% with a BMI of 30, and 36% with a BMI of 40 [23]. New post-operative positioning-related brachial plexus palsies were only found in extremely obese patients (BMI ≥ 40) [23]. Many studies have shown the relationship between obesity and PRSC; our results also show BMI as a very strong predictor of position-related changes and injury. Clearly, patients with higher BMIs are at risk for these injuries which suggests that special attention should be given to ensure appropriate/adequate padding of all peripheral nerves during surgery or, in extreme cases, consideration should be given to alternative positioning options for the procedure. Stretch, 5–15% beyond the resting length, is one of the main mechanisms of ischemia in the prone Superman position. Ischemia is due to compression of the intraneural capillaries leading to decreased perfusion pressure and can result from compression or augmented by intraoperative hypotension [35].

Our results also showed that individuals older than 65 years of age are at a higher risk for PRSC. Daubs et al. studied the complications and outcomes of patients 60 and older in spinal surgery. Increasing age was a significant factor ($p < 0.05$) in predicting the presence of perioperative complications, such as neurological deficit, myocardial infarction, pulmonary embolus, pneumonia, and infection [19]. We speculate that because older people are more fragile and take more time to recover, they are more likely to have perioperative complications.

Our results also showed abnormal IONM baselines as a risk factor for PRSC [p value = 0.04; odds ratio 0.61 (0.38, 0.98)]. We showed that patients with abnormal upper extremity SSEP baselines, which included pre-position delay

Table 3 Risk factors

Predictive factors	Significance	Odds ratio	95% CI for odds ratio
Female	< 0.01	5.45	(3.29, 9.03)
Age > 65	< 0.01	2.20	(1.29, 3.75)
Age > 80	0.377	1.56	(0.58, 4.21)
Overweight	< 0.01	14.29	(7.46, 27.37)
Obese	< 0.01	3.56	(2.37, 5.34)
Smoke	< 0.01	6.93	(3.61, 13.27)
Diabetes mellitus	0.954	1.02	(0.61, 1.69)
Hypertension	< 0.01	2.30	(1.52, 3.50)
Cardiovascular disease	0.957	0.98	(0.54, 1.80)
Peripheral vascular disease	0.645	1.28	(0.44, 3.70)
Abnormal baselines	< 0.01	4.32	(2.83, 6.58)
Procedure time > 200 min	< 0.01	1.99	(1.31, 3.03)

CI confidence interval

This table shows the multivariate logistic regression results including their significance and odds ratios in predicting positioning-related changes

and asymmetric SSEPs, are more likely to incur intraoperative PRSC. We believe that patients with abnormal baselines tend to have worse pathology, leading to a more eventful surgery. This confirms Alvin et al.'s study who reported that patients who developed ulnar neuropathy had asymptomatic preexisting abnormal conduction in the contralateral nerve [36].

This study showed that the so-called "superman position" is associated with a higher risk of PRSC, substantiating Kamel et al's study [37]. The main mechanism of injury is via stretch, and injury usually occurs along the length of the brachial plexus. Lateral neck rotation and arm abduction > 90° should be avoided as they can also stretch the brachial plexus [10]. Position modification strategies that resulted in no post-operative peripheral nerve injury included correcting extreme elbow flexion and extension, decreasing shoulder abduction, releasing shoulder traction on tucked arms caused by taping down the shoulder, and moving the upper extremity into the original position if the position had been modified [37].

Gender, smoking, and hypertension were also found to be risk factors due to their high odds ratios. A retrospective review of 1223 thoracic and lumbar anterior spinal fusions identifying risk factors for perioperative complications reported women were at a higher risk than males [38]. As women have a higher percentage body fat than do men, 25% versus 15% [39] respectively, perhaps many women have similar problems to overweight or obese patients. The higher fat content in women may pose a potential risk for perioperative complications and lead to positioning related changes. Welch et al. completed a study on 380,680 cases and showed that hypertension and smoking are significantly associated with perioperative peripheral nerve injuries and complications. Hypertension is a chronic disease process that affects blood flow and thus may leave the nerve more susceptible to injury. Hypertensive patients have a propensity for hemodynamic instability and the predisposition for other comorbidities associated with peripheral nerve injury, which may also increase their risk of intraoperative complications such as PRSC [9]. Smoking increases insulin resistance which leads to fat accumulation. Heavy smokers, many of whom, tend to engage in risky behaviors such as decreased physical activity and poor diet which contribute to weight gain have greater body weight compared to light smokers [39].

We examined the impact of PRSC on greater hospital length of stay, discharge disposition, and procedure time. Our study did not show a significantly increased hospital length of stay or an associated discharge disposition, whether home or nursing home. This is not surprising because all the UE SSEP changes were never ignored and allowed to persist, even if all affected SSEP changes were not completely resolved [10, 37].

69 of the patients were declared to have PRC though 10 of them did not have changes in the erbs point channel, only in the cortical and subcortical channels. This was because no clear criteria exist in the literature on what constitutes a quantitative change due to position and empirically surgical intervention is based on the criteria mentioned in the methods. All responses do not need to be abolished or changed to make an intervention. We do plan to do an extensive quantitative analysis of the response and plan to submit that as a complete new publication as the alarm criteria for a position change deserve to be a standalone document.

There are several limitations present in our study. There was no standardized method of documenting neurologic examinations by many different surgeons, there may have been differences in grading each patient's motor and sensory functions. The duration of neurological deficits was not recorded in the patients' charts so all types of deficits, transient, permanent, and developed later, were included in our analysis. We partly overcame this limitation by reviewing multiple documentation of perioperative neurological examination.

5 Conclusions

Based on the calculated odds ratios, patients with PRSC are more likely to have abnormal baselines, higher BMIs, and undergo longer surgical procedures. We recommend IONM for these cases to detect PRSC and to minimize the likelihood of iatrogenic injury for patients in the prone position. Gender, hypertension, and smoking were also found to be risk factors from their odds ratios.

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